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to the constant number in Balmer's formula, which is given on p. 230.

The frequency

$$N = \frac{1}{\lambda}$$

is stated to be found for the hydrogen lines from the equation—

$$N = 2748 . 13 \, (1 - 4m^{-2})$$

and a reference is given to the *Phil. Mag.* 1890. But I find that—

$$N = 2742 . 625 \, (1 - 4m^{-2})$$

or

$$\lambda = 3646 . 141 \, \frac{m^2}{m^2 - 4}$$

gives the standard wave lengths with much greater accuracy.

On the Comparison of Reflector and Portrait Lens Photographs.
By E. E. Barnard.

In the *Monthly Notices* for 1896 April Dr. Roberts has given a comparison of the photographic plates made with his 20-inch reflector, and with two portrait lenses of $3\frac{1}{2}$ and 5 inches diameter. These small lenses have foci of 9·56 inches and 19·22 inches respectively, while the 20-inch reflector has a focus of 98 inches. At the close of his paper Dr. Roberts takes occasion to criticise several of my star photographs, now in the possession of the Royal Astronomical Society, which were made at Mount Hamilton with the 6-inch Willard lens of 31 inches focus.

These comparisons of the portrait lenses with the reflector might be objected to upon several grounds. First of all, the only claims of superiority that I know of which have been urged in favour of the portrait lens are its advantages, on account of small scale and wide field of view, in showing very large and faint nebulous areas, the phenomena of the tails of comets, and the structural forms of the Milky Way. In these special fields it is supreme, and likely to remain so until some better instrument than any hitherto used has been devised for this class of work.

The method of comparison by counting the number of stars shown on equal areas of the reflector and portrait lens plates is not only not the best one, but is very unfair to the short focus lens. On account of the smaller scale of the portrait lens, what will appear as several stars on the reflector plate will often coalesce into one star on the plates with the portrait lens, and for this reason a count of the stars, particularly with a long exposure, must necessarily be favourable to the larger instrument.

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A fairer way, and one freer from error, would be to select regions free from bright stars, on a plate of sufficiently short exposure to make identification of the stars an easy matter, and then see if the faintest stars were wanting on the small plates. An estimate of the difference of magnitude between the faintest stars that are shown on the small plates and the faintest on the reflector plates, will tell more concerning the relative penetrating powers of the two instruments than all the counts of individual stars that could ever be made, and this is equally fair to the reflector and the portrait lens.

To further show the fallacy of the method of counting the stars in a test of this kind, it is only necessary to call attention to the fact that a very slight difference in the actual magnitudes of the smallest stars shown on the two plates may double or treble the number of stars revealed by the larger instrument. In the Milky Way this difference would be still more increased.

In reference to my photographs which Dr. Roberts mentions, I would say that there must have been an interchange of dates on the two positives of the neighbourhood of γ *Cassiopeiæ*, which were sent to the R.A.S. The one he speaks of as having been made 1894 February 2, with three hours' exposure, can scarcely be the one he has examined, for on that plate γ *Cassiopeiæ* is 8° from the middle of the field, and at a point where all the small stars are defective from distortion. No one should attempt to count the stars under these conditions, and hence I assume this is really not the plate referred to (see note at end of this paper). There is another plate near the region of γ *Cassiopeiæ* which was made 1894 February 6, with $1^h\ 47^m$ exposure on a constantly thickening sky, which finally stopped the exposure. The effective exposure on this plate would be far less than this time, and I think an hour and a half would be a too liberal estimate of the equivalent time under ordinary conditions, and perhaps one hour would be nearer the mark. On this last plate γ *Cassiopeiæ* is about 4° from the centre; and in fairness no one ought to select such a position on a portrait lens plate for comparison with the central part of another picture. On this plate (assuming it is the one used by Dr. Roberts) he succeeded in counting 1,300 stars in an area of 2° square about γ *Cassiopeiæ* as a centre. In this same area he counted the following on his own plates with $2^h\ 12^m$ exposure :—

With $3\frac{1}{2}$-inch lens, 1,080 stars.
With 5-inch lens, 2,610 stars.
With 20-inch reflector, 17,100 stars.

After seeing his article, I was curious to know how many stars were really shown on my plate, in the exact region examined by him. Over a glass positive from this negative I placed a square aperture 2° × 2° with γ *Cassiopeiæ* in the centre. On the positive was ruled a series of small squares to avoid confusion in the counting. This space was examined with a suitable magni-

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fying power, and the result was that 3,396 stars were counted where Dr. Roberts discovered only 1,300. This seems to me to speak very favourably for the performance of the Willard portrait lens under trying circumstances. The image of γ *Cassiopeiæ* on the original negative is round and sharp, and only 4′·5 in diameter. On his own plates Dr. Roberts found, with 2^h 12^m exposure, the image of γ *Cassiopeiæ* had the following diameters:—

With 3½-inch lens, 18′·7.
With 5-inch lens, 10′·2.
With 20-inch reflector, 16′·9.

It would appear that these images are abnormally large compared with those of the Willard lens.

Dr. Roberts mentions the lack of details in the two fan-shaped nebulæ close to γ *Cassiopeiæ* which were discovered with the Willard lens. This was doubtless due to the short exposure and the thick sky. The night was not suited for the photography of nebulæ. In speaking of these two nebulæ Dr. Roberts says: "I may here state that the two fanlike nebulæ which have been referred to, were faintly shown on a photograph of the region of γ *Cassiopeiæ*, which was taken with the 20-inch reflector on 1890 January 17, but at that time I thought they were due to stains on the film." Considering the importance of these nebulæ, it is to be regretted that Dr. Roberts did not repeat his exposure to see if the markings were only stains on the plate. The discovery of these interesting objects might then have been credited to the 20-inch reflector. Referring to this same picture of 1890 January 17 in his book of celestial photographs, Dr. Roberts distinctly discredits the existence of any true nebulosity about γ *Cassiopeiæ.*

He has also taken occasion to notice two plates of the neighbourhood of the Pleiades made by me at Mount Hamilton. The first of these was given four hours' exposure 1893 December 1. Time has always been too precious to warrant the making of exposures on objects which were manifestly unsuited for my instrument, and those which had been successfully photographed elsewhere with instruments better adapted to the purpose. One of the objects thus recognised as beyond my reach was the Pleiades, and therefore I never made any photographs of that cluster to show the closer nebulosities which are mixed up with the brighter stars. Objects of this class belong entirely to large telescopes. The first of the photographs was made in the hope of showing certain vague nebulosities I had previously seen with the telescope north of the Pleiades. For this reason the cluster itself was placed some distance from the centre of the field, the suspected nebulous region being given preference of position. The positive of this plate sent to the R.A.S. was not sent in competition with photographs of the cluster made with more powerful telescopes, but simply to show the general appear-

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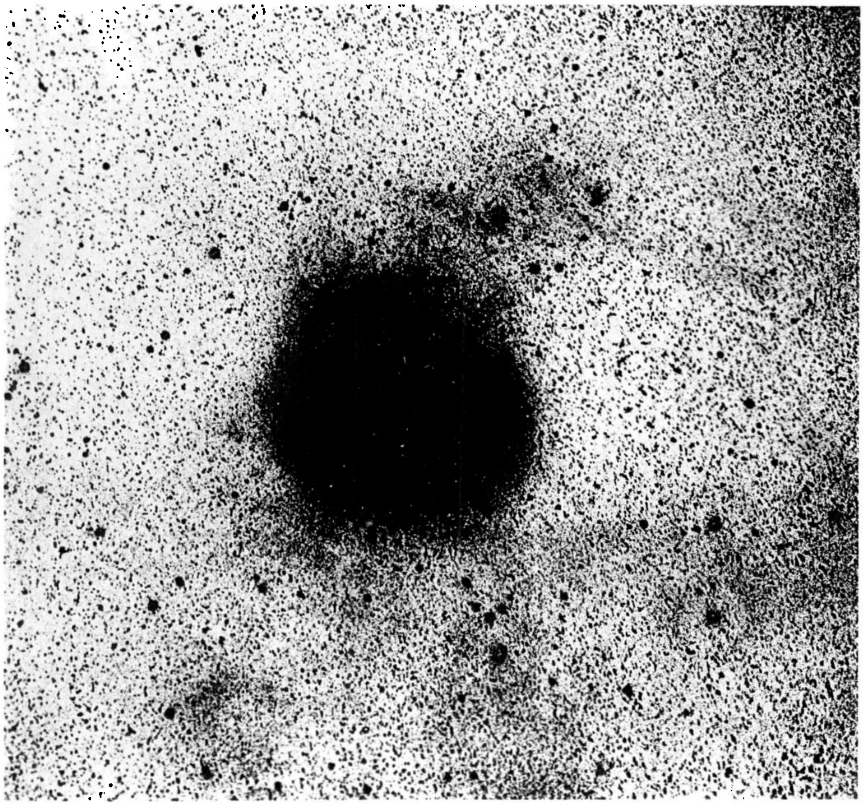
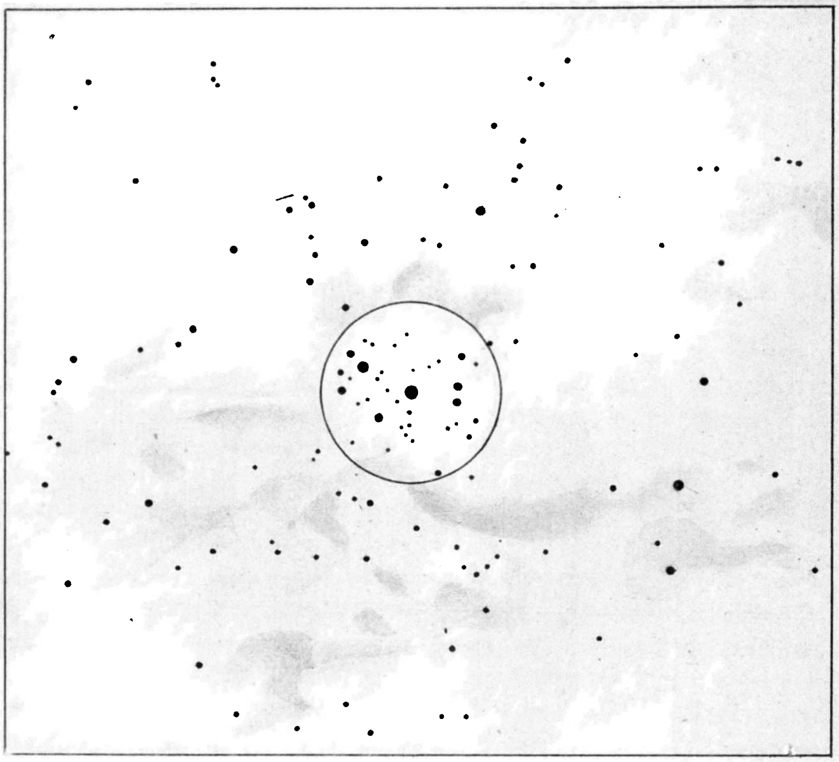


EXTERIOR NEBULOSITIES OF THE PLEIADES.

E. E. Barnard.



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ance of the stars in that part of the sky, and as a supplement to the one with two nights' exposure, on which the star images were not good. On this four-hour plate the Pleiades are 3° from the centre of the field, and therefore not in the best position to show the faintest stars in that vicinity. On this positive Dr. Roberts counted in a space 2° by 2°, with η central, 825 stars, against the following with 2^h 50^m exposure made at his observatory:—

With the 5-inch lens, 953 stars.
With the 20-inch reflector, 3,470 stars.

By the same method used with γ *Cassiopeiæ* and with η central, I counted in the same area 1,042 stars distinctly shown. Why he should find so few stars on my plates when so many exist, I would not attempt to explain. The image of η *Tauri* on the original negative is $3'\cdot9$ in diameter, and is round and sharp. Traces of the exterior nebulosities are shown on this plate on each side of the cluster, and this led me to place the Pleiades more central in the long exposure made afterwards.

The other photograph of this region was taken 1893 December 6 and 8, and the whole exposure was 10^h 15^m. The exposure was begun December 6, but the following night was cloudy, and the plate therefore lay in the camera from the 6th to the 8th. The camera box was of wood, which on Mount Hamilton is always subject to much change by shrinkage or expansion. Under these conditions it is really remarkable that after two entire days, one entire night, and parts of two other nights, it was possible to again so perfectly match the star images at the second exposure that it requires close examination to detect a slight overlapping of the star discs. With all these difficulties the picture admirably serves its purpose, since it was only intended to show the exterior nebulosities to which everything else was sacrificed. Dr. Roberts says of this picture, that the star images are elongated and overlapping; and he should have seen that it could not fairly represent a continuous exposure of $10\frac{1}{4}^h$. I fail, however, to see the force of his reasoning that because of these conditions, "some doubt would be cast on the reality of the distant nebulosity which is shown on the plate."

In reference to the slight elongation of the stars on this plate, mentioned by Dr. Roberts, where the plate was in the camera for over fifty hours, I think he can appreciate the difficulty of keeping the stars round even with short exposures, as will be seen by reference to his book of photographs, where quite a number of the pictures show defective star images. Plates 42 and 45 show strongly this elongation of the star images, and others in a lesser degree. Yet after all I fail to see how the slight elongation or overlapping of the stars in the Pleiades picture can have the least effect on the nebula itself, since the nebulosity is a surface and not a point of light. It would certainly get the full

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benefit of the entire exposure, though the stars would not. On this plate the long exposure seems to have only slightly increased the diameters of the bright stars; the diameter of η measures $4'{\cdot}5$ against $3'{\cdot}93$ on the four-hour exposure. Both original negatives show considerable detail among the interior nebulosities, though the positives sent to the R.A.S. may not do so. The matter was not deemed of sufficient importance to make special positives for that purpose.

At a meeting of the B.A.A. on April 29, Dr. Roberts took a further opportunity to object to these star pictures, and is reported to have said the exterior nebulosities shown on my Pleiades photographs "were not nebulosity, and he made the assertion without fear of anyone proving the contrary." That these nebulosities exist as shown on my photographs there can be no doubt whatever. Indeed, it was the knowledge of their existence by visual observations alone that led me to make the photographs. The previous experience of Dr. Roberts with the diffused and faint nebulosity about 15 *Monocerotis* (*M. N.* vol. lvi. No. 2)—which was first shown to exist by the Willard lens—the discovery of which he at first discredited, might warrant some hesitation on his part in denying the existence of a similar region about the Pleiades.

In this connection I may mention that through the courtesy of Dr. Roberts I have a small glass positive of his photograph of the region of 15 *Monocerotis*. To my surprise, I find that his picture does actually show faintly this nebulosity, the existence of which he undertook to disprove by this very photograph. It is not shown so strongly as with the portrait lens, but all that is wanting to show it fairly well with his reflector is a somewhat longer exposure, and a larger plate to give more sky about it for contrast. The faint nebulosity will cover an entire plate of the size he now uses. I have compared his positive with an enlargement of my photograph of this region, not to count the stars, but to single out the faintest stars on his picture to see if they existed on mine. I was surprised to find how nearly my plate succeeded in showing every faint star on the other. There were some of his very faint stars not shown on my plate, but there would be scarcely half a magnitude between his faintest and my faintest. I am not sure but that fainter stars yet might have been shown on my plate were it not that the region possible for comparison on the two plates was covered with strong nebulosity on my plate in which very faint stars may have been lost.

Notwithstanding his condemnation of the faint nebulosities shown by portrait lenses to exist in certain parts of the sky, Dr. Roberts claims that his photographs of the dense globular clusters show essentially all these objects to be nebulous. As instances of this supposed nebulosity, he cites photographs of the following clusters, shown in his book of photographs of star clusters and nebulæ:—Messier 53, plate 29; M. 3, pl. 31; M. 5, pl. 33; M. 13, pl. 34; M. 12, pl. 35; M. 10, pl. 36;

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M. 92, pl. 37; and M. 15, pl. 47. Speaking of these clusters, he says: "While the whole of the nebulosity has not been absorbed or utilised in the formation of the stars, some of the nebulosity, varying in extent and density, is shown on the photographs to be present in each cluster." He further endorses this statement in the notes in connection with the individual pictures.

If one examines the photographs referred to, the apparent nebulosity in most of them seems to be in all probability a photographic effect only, due to the crowding of the bright stars, combined with an unsteady atmosphere, and a lack of exact focus, and also further increased by the great enlargement from the originals. Take, for example, the cluster M. 3, which is perhaps the most nebulous-looking cluster in the entire book. If the small stars scattered everywhere on this plate are examined it will be seen that they are hazy and ill-defined like those of the same size in the cluster. These exactly resemble the photographic image of an out-of-focus star with too much subsequent enlargement. To prove the nebulosity of this cluster, Dr. Roberts compares this photograph with those of the very wide and loose clusters M. 11, pl. 40, and M. 37, pl. 18, and the double cluster of *Perseus*. In the latter the stars are widely separated, and there is consequently less chance of their running into each other through a lack of focus or by bad seeing. Such photographs cannot properly be used to prove the nebulosity of a closely packed globular cluster. If we look at the plate of M. 11, it will be seen that the small stars are ill-defined as if somewhat out of focus. A dense clustering of these stars would present a nebulous appearance, especially if the magnification was increased to correspond with that of the globular clusters. As a further example of this effect take plate 12, "Region of *Nova Aurigæ*." The stars scattered over this plate are hazy as though not exactly in focus. Compress these into a globular cluster, and increase the enlargement four times, and I think the result would be a splendid specimen of a "nebulous" globular cluster; and yet I believe Dr. Roberts has used this very picture to prove that *Nova Aurigæ* was not nebulous.

If we should treat the small stars shown in the plate of the nebula of *Andromeda* in this same manner, another "nebulous" globular cluster would be the result. Another good example is plate 49, where the small stars all over the plate are ill-defined and hazy. There are also other plates of this kind that might be mentioned—viz. plates 14 and 38, where an imperfection of focus produces a defective and hazy appearance in the stars which might well lead to apparently highly interesting results if combined into a globular cluster. I have examined these globular clusters in the sky with the most powerful telescopic means, and have found it impossible to decide whether they were nebulous or not when the seeing was at all indifferent; the bad seeing seemed to produce in them a haziness, much like nebulosity, by

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the mixing of stray light. Under first-class conditions, however, when the air was very steady, the impression was that these clusters were free from true nebulosity.

A last word as to the relative value of the portrait lens and the reflector. The superiority of the one over the other will depend entirely on the object photographed. A short-focus portrait lens is only intended to show large structural details, such as the phenomena of comet tails, the great diffused nebulosities of the sky, the cloud-forms and details of the Milky Way, &c. When used for such work, no other form of instrument can equal it. When small details in limited areas are wanted, a larger instrument must be used, such for instance as Dr. Roberts's large reflector. For the small details in an object like the *Orion* nebula, it would be absurd to expect the best results from the small scale of a portrait lens. Yet the great curved nebula covering a large part of *Orion* is not only out of the reach of the large telescope, but it is best shown with an instrument beside which even the modest portrait lens is a giant. Still it is easy to imagine how poor these details shown in the great *Theta* nebula by a 20-inch reflector would appear, compared with those shown in another telescope with light and scale proportionally increased. If one compares the magnificent photograph of the cluster M. 13, in *Hercules*, made by Mr. W. E. Wilson, at Daramona, Ireland, with the photograph of the same object as shown in Dr. Roberts's book, with the same exposure, this difference will be more readily appreciated; and yet in this case the increase of aperture was only 4 inches.

In conclusion, let me say that specimens of my comet and Milky Way photographs, made with a portrait lens, are in the possession of the Royal Astronomical Society. An unprejudiced inspection of these will show their value to the science of astronomy. It must be understood, however, that they are to be looked at as pictures of the objects they represent, and are not to be examined with a microscope for details which in the nature of things it is impossible for them to show.

Kenwood Observatory, Chicago, Ills.:
1896 *June* 19.

P.S.—To see if any mistake had been made in dating the two positives of the region near γ *Cassiopeiæ* that are in the possession of the R.A.S., I sent tracings of them to Mr. Wesley, the Assistant Secretary of the R.A.S. He has kindly returned these tracings to me, since the above paper was written. He finds that they agree in date &c. with the positives, so that no mistake had been made. From this it appears that Dr. Roberts did actually use the 1894 February 2 photograph for comparison where the image of γ *Cassiopeiæ* is close to the edge of the plate and 8° from its centre, and where the small stars are either defective or entirely lost through distortion of the field !—E. E. B.